Core-Collapse Astrophysics with Supernova Neutrinos

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Workshop on Underground Detectors
Investigating Grand Unification

Brookhaven National Laboratory
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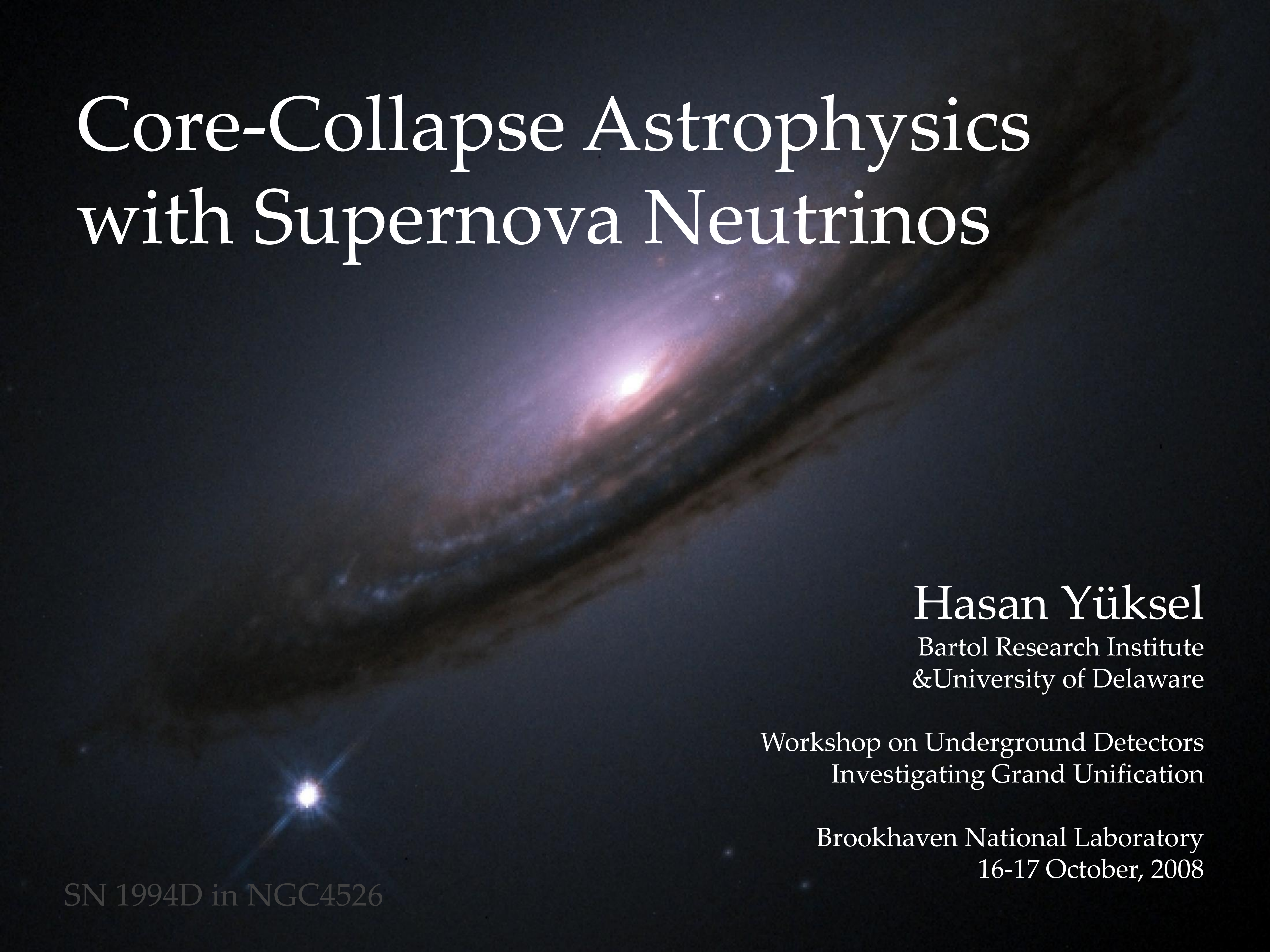


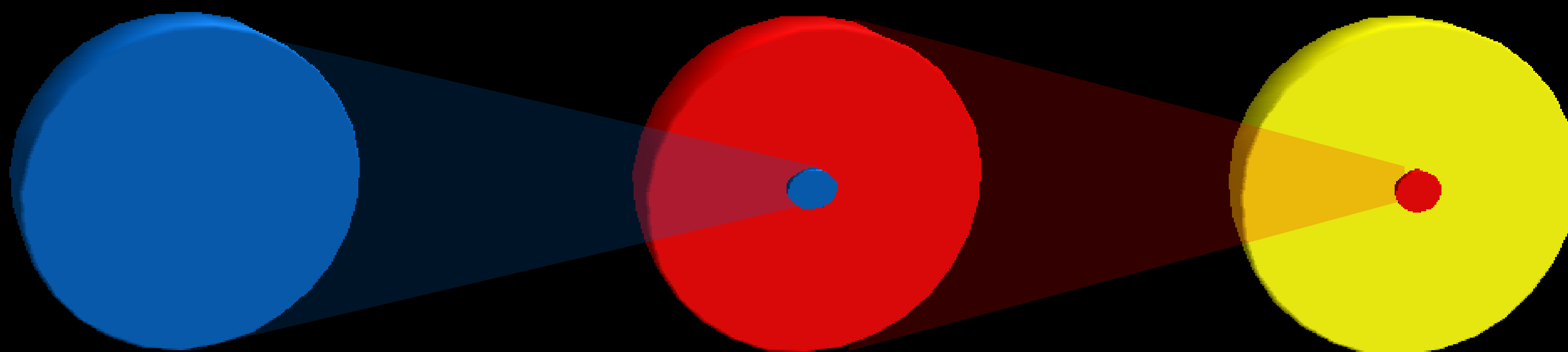
SN 1994D in NGC4526

Core-collapse SN & Neutrinos

proto-neutron star
~10 km ~1.4 $m_\odot$

iron core
~10^3 km ~1.4 $m_\odot$

massive star
~10^8 km ~10 $m_\odot$

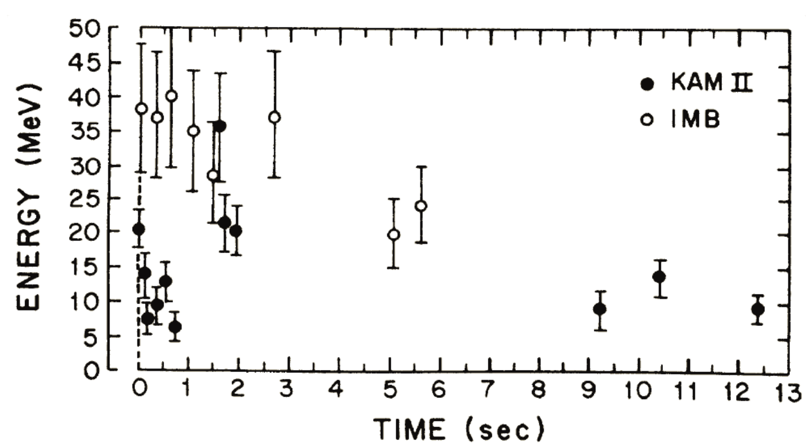


$$\frac{3}{5}\frac{G\,M_{NS}^2}{R_{NS}} \approx 3 \times 10^{53}\text{ergs}\,\frac{(M_{NS}/1.4M_\odot)^2}{R_{NS}/10\text{km}}$$

~ 1/6$^{\text{th}}$ rest mass of the Sun

neutrinos ~ %99 K.E. of the explosion ~1% radiation ~ 0.01%

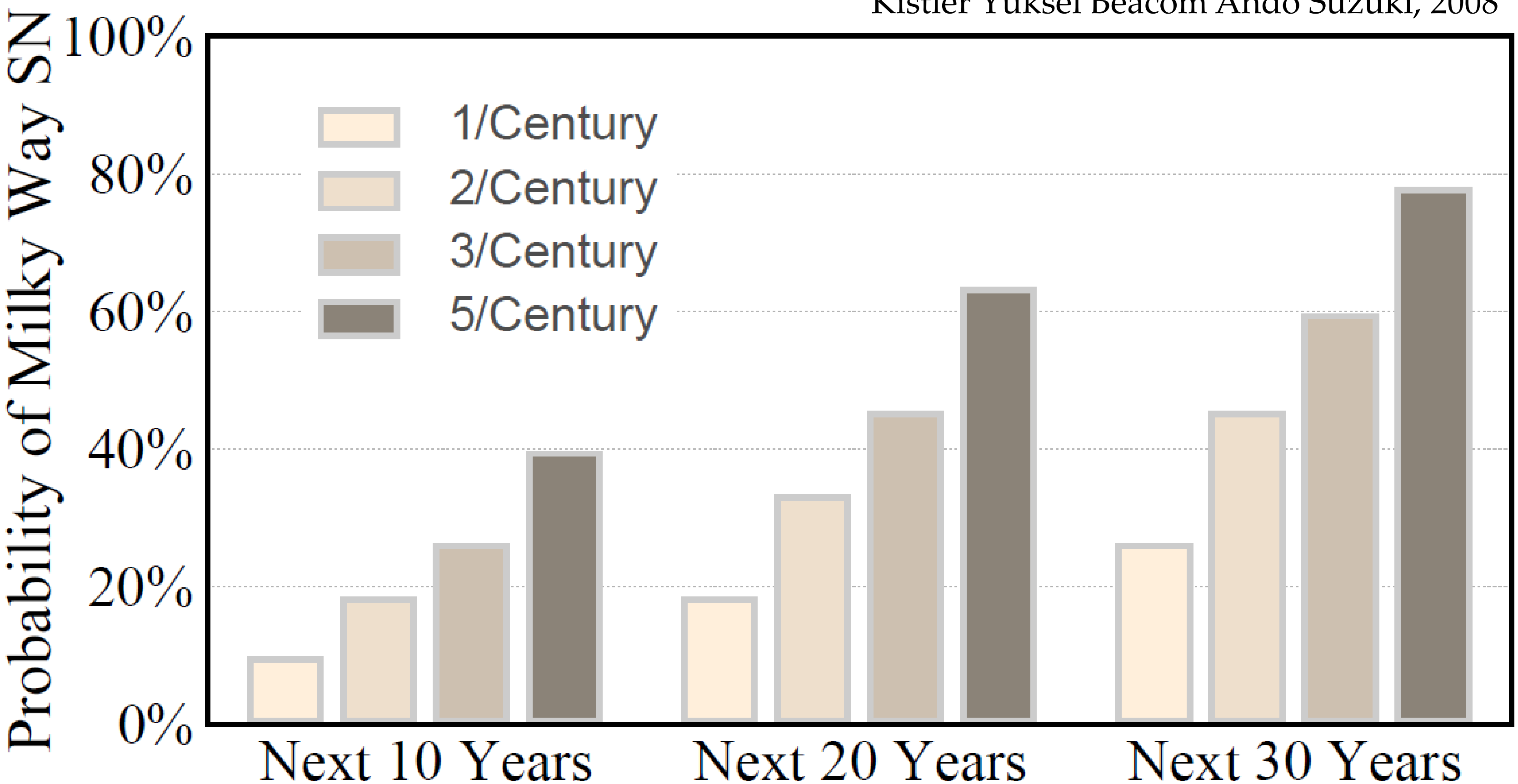
SN 1987A



ENERGY (MeV)
TIME (sec)
KAM II
IMB
0
5
10
15
20
25
30
35
40
45
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13

But SN in our Galaxy is Rare

Kistler Yüksel Beacom Ando Suzuki, 2008



We should look for neutrinos from elsewhere while waiting

Brief (pre) History of the Diffuse Supernova Neutrino Background

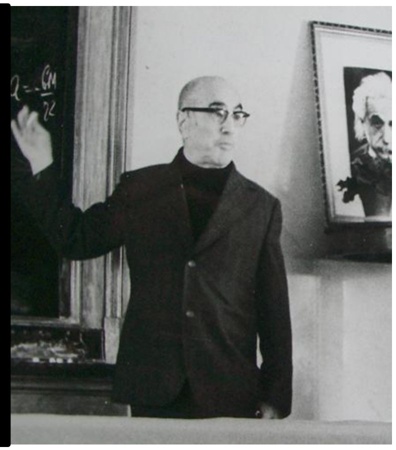
- prehistory:
  - zeldovich guseinov (1964,65)

$\sim 10^5$ cm^{-2} s^{-1}

(density of collapsed matter over estimated by ~1000)

<u>current limits:</u>

$< 10^2$ cm^{-2} s^{-1}



- Initial calculations:
  - bisnovatyi-kogan seidov (1982)
  - krauss glashow schramm (1983)
  - domogatskii (1984)
  - dar (1985)
  - woosley wilson mayle (1986)

- more recent studies:
  - totani sato (1995)
  - malaney (1997)
  - hartmann woosley (1997)
  - kaplinghat steigman walker (2000)
  - ando sato totani (2003)
  - fukugita kawasaki (2003)
  - strigari beacom walker zhang (2005)
  - yuksel ando beacom (2006)
  - lunardini (2006)
  - daigne olive sandick vangioni (2005)
  - iocco mangano miele raffelt serpico (2005)
  - yuksel beacom (2007)

among many more recent others ...

Diffuse Supernova Neutrino Background

History of Star Formation in the Universe

- Core Collapse SN Rate per unit star formation

Neutrino Emission per Supernova

- Average energy of a given flavor
- Total Luminosity emitted in each flavor
- Oscillations between flavors

Detection

- Detector Size
- Neutrino Cross Sections
- Competing Backgrounds

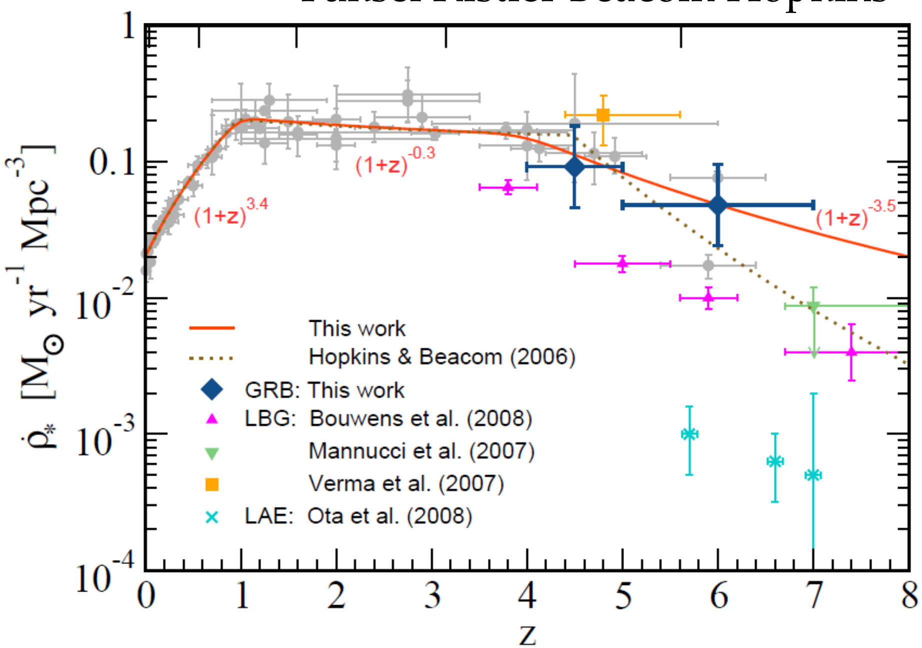
Standard Cosmological Assumptions

- Hubble Constant
- Omega Matter
- Omega Lambda

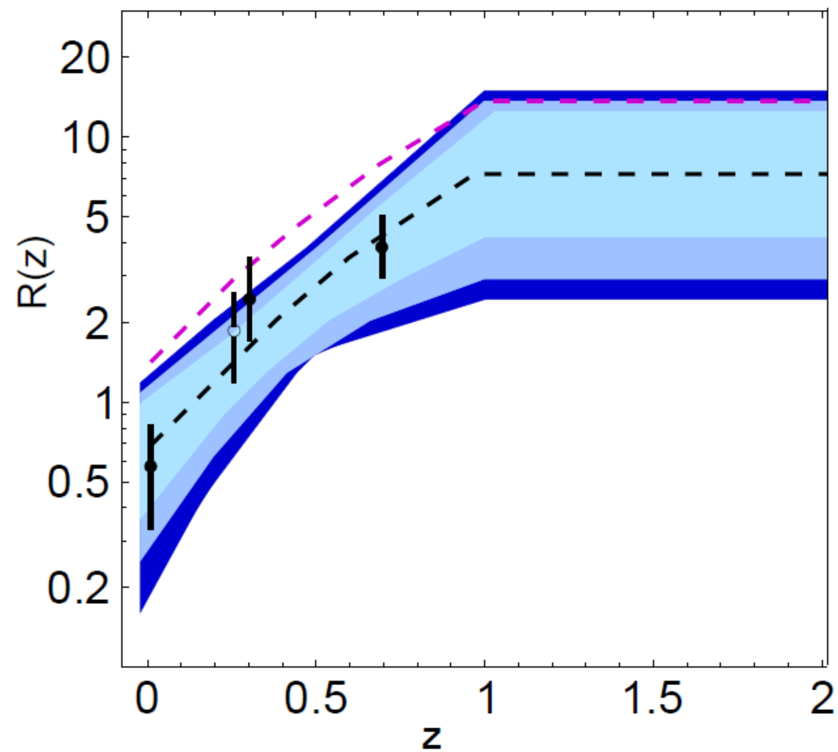
$$\psi(E_+) = \frac{c}{H_0}\sigma(E_\nu)N_t \int_0^{z_{max}} \phi(E_\nu[1+z])\frac{R_{SN}(z)}{h(z)}dz$$

Star Formation Rate

Yüksel Kistler Beacom Hopkins



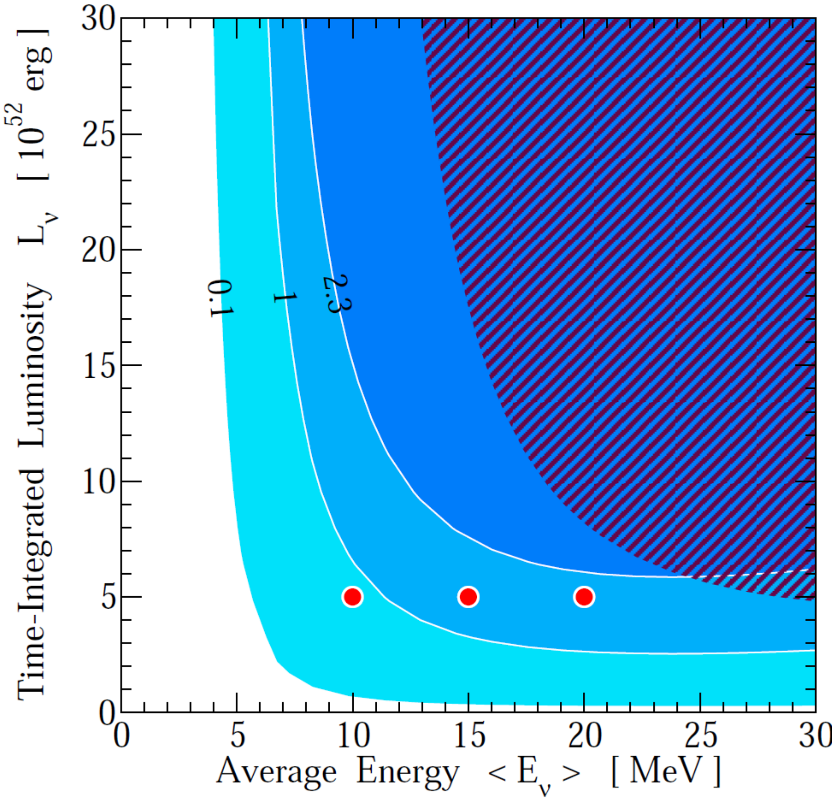
Lunardini

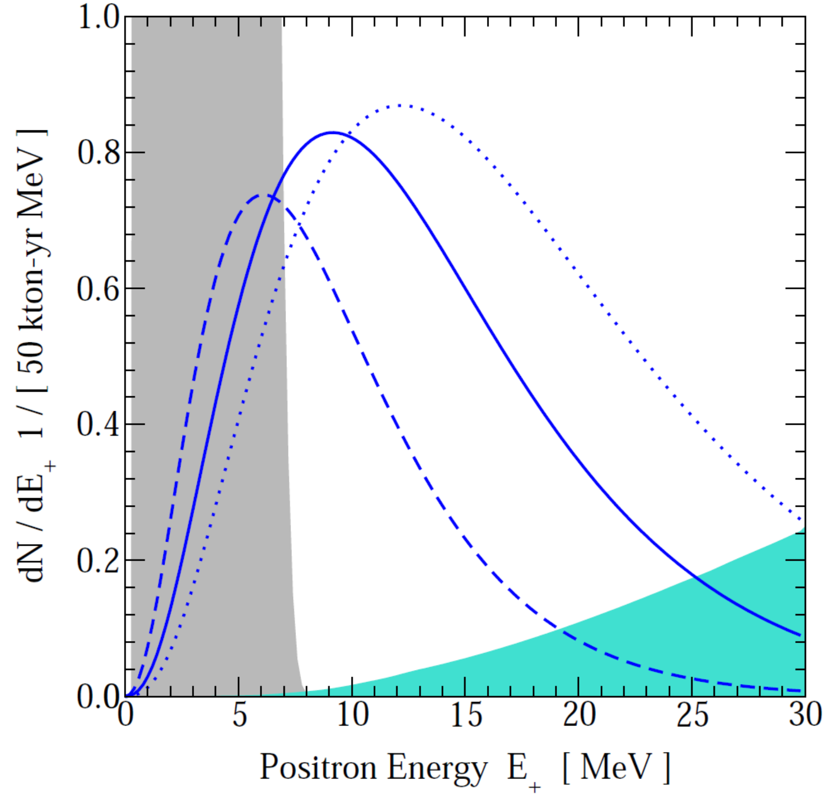


Astronomers will measure star formation rate better eventually
Need to better understand SFR → SN rate

Neutrino Emission per Supernova

Beacom Strigari Yüksel, in preparation since 2005

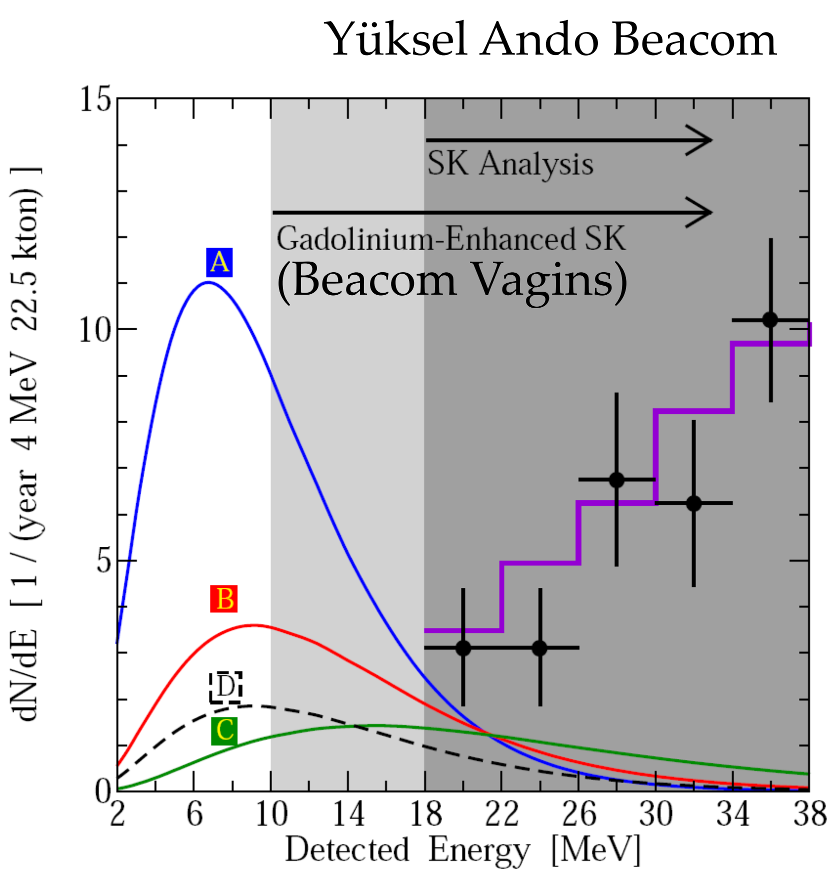


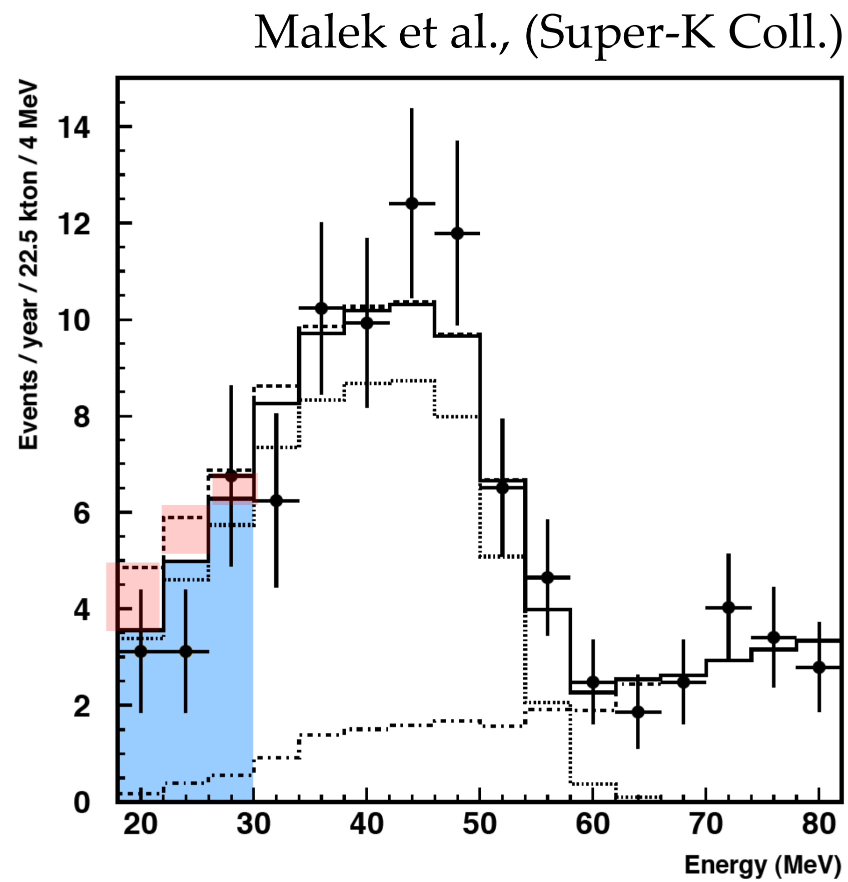


Event Rate in [8-20] MeV per 10 kton-yr

Need to know the Backgrounds?

Super-K Upper Limits

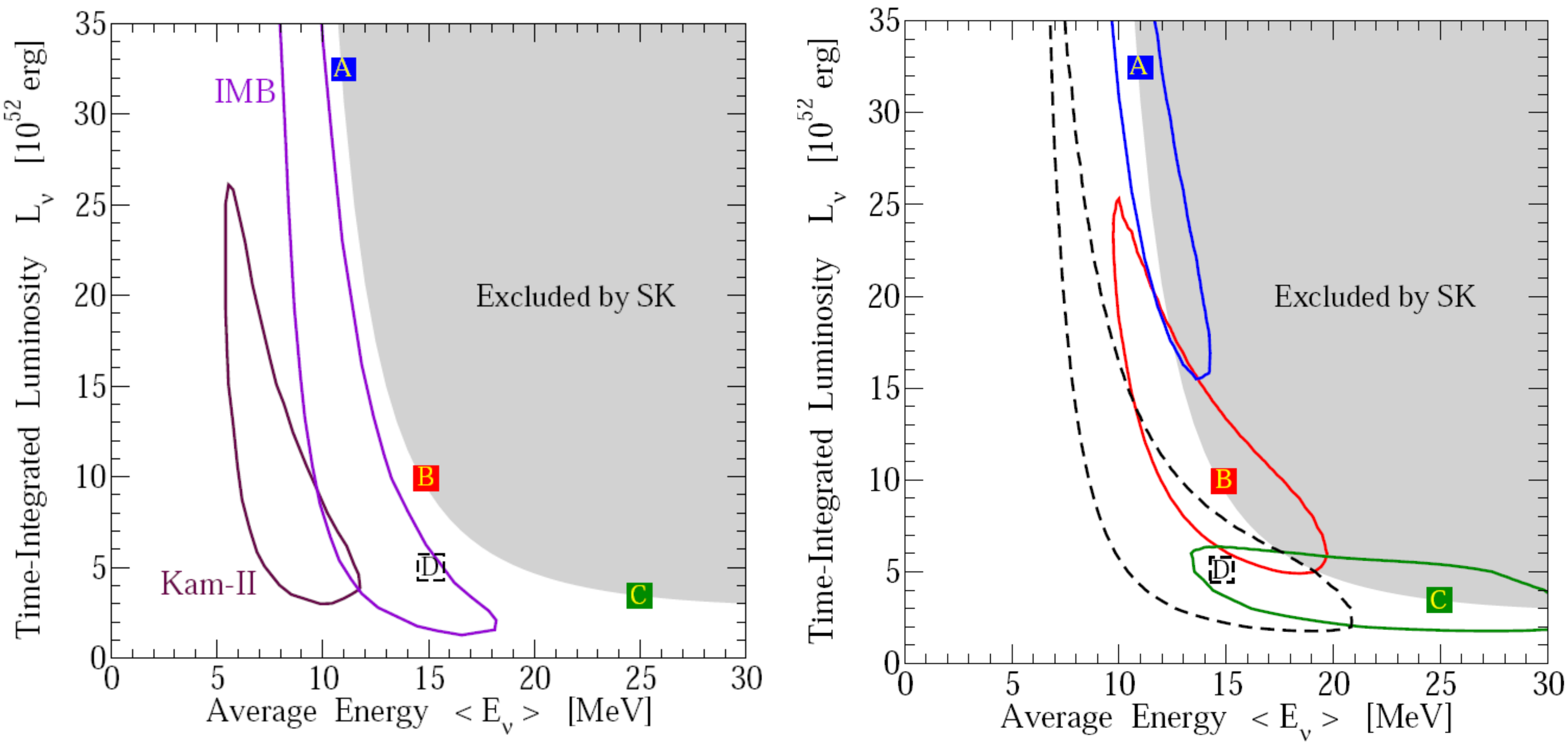




Super-K Limit: 1.2 cm^{-2} s^{-1} (>18 MeV)

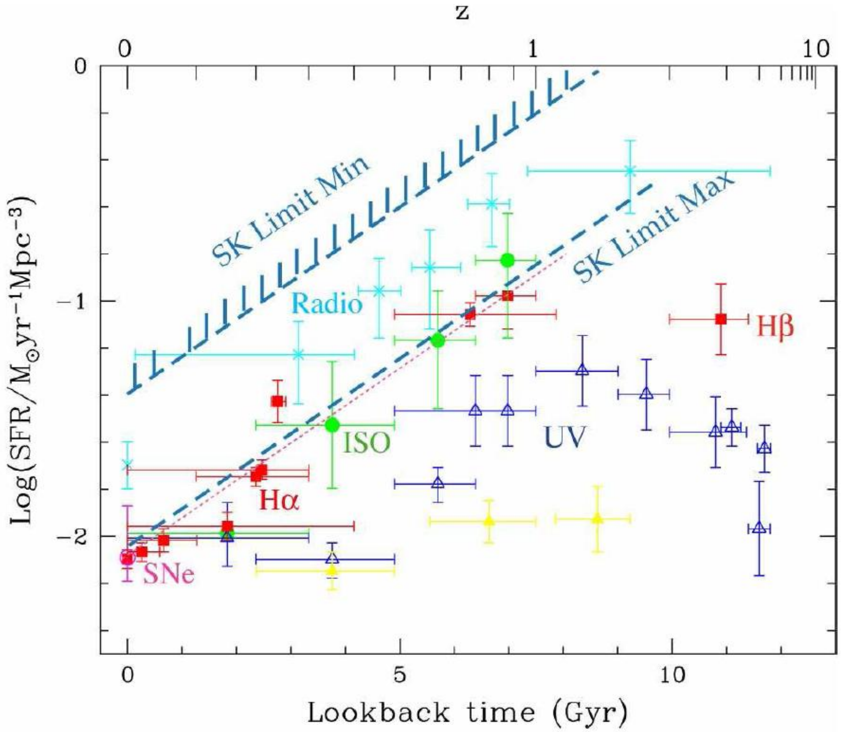
Potential of Gd Enhanced Super-K

Yüksel Ando Beacom



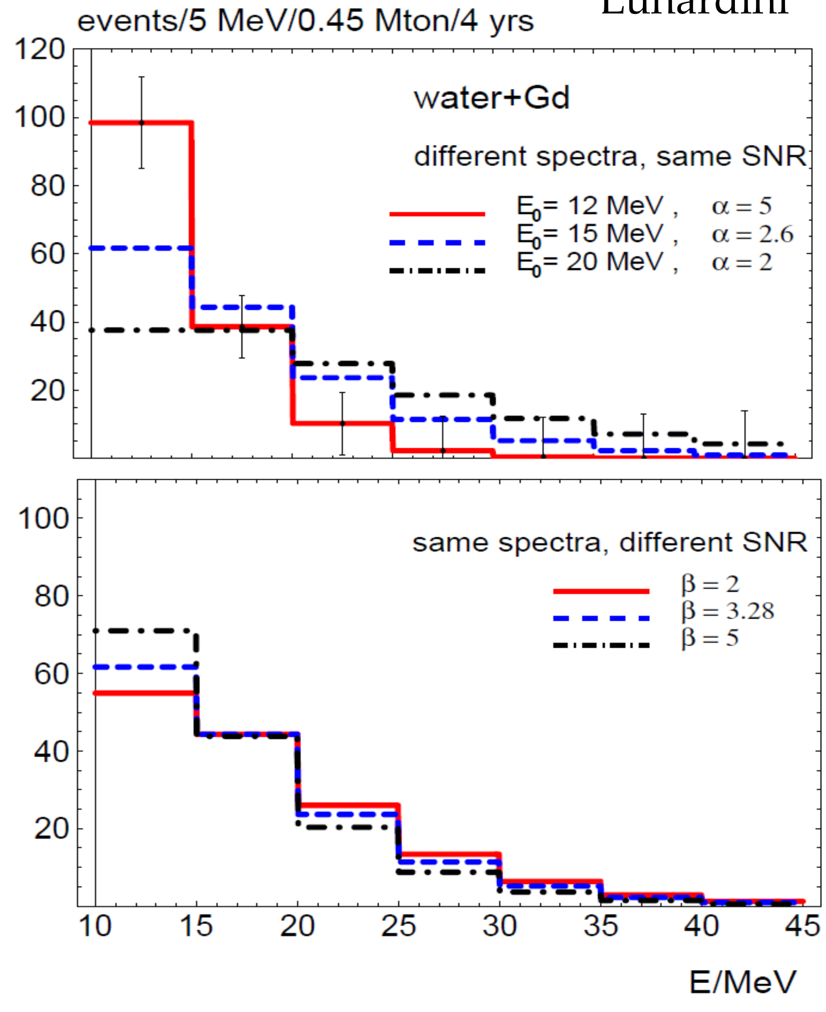
- the time-integrated luminosity and average energy may also constrain the explosion energy and protoneutron star opacity

Testing SFR with DSNB



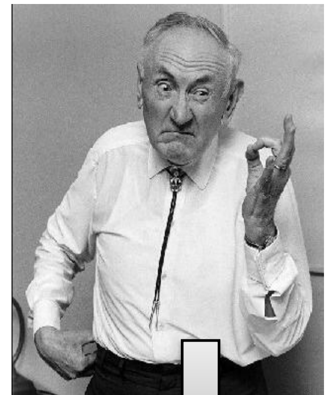
Fukugita Kawasaki
Strigari Beacom Walker Zhang

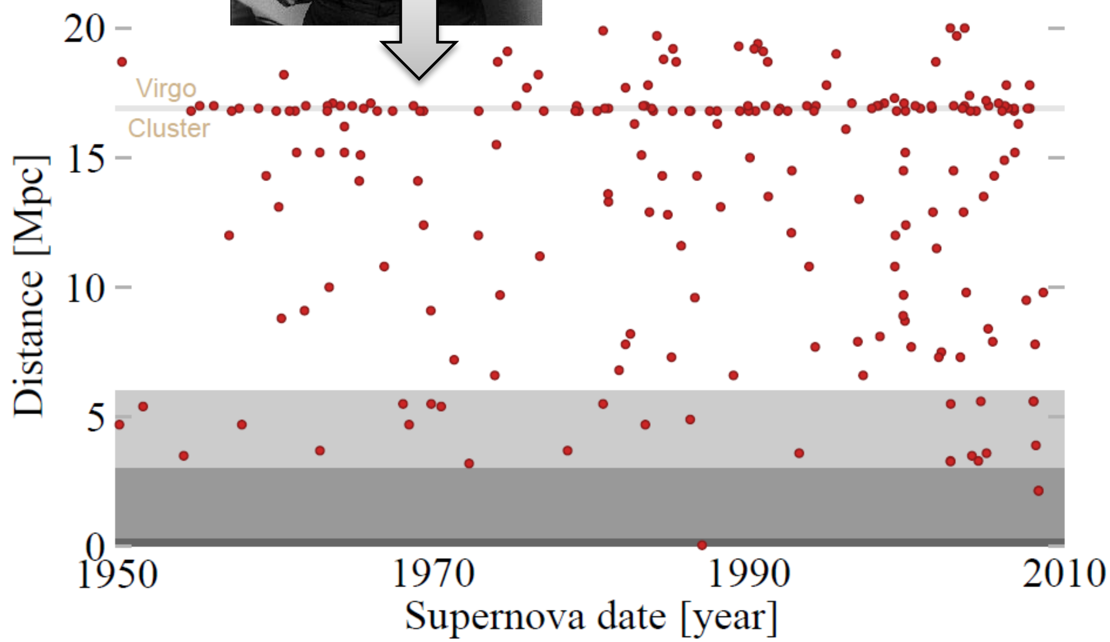
Lunardini



Supernova in the Neighbourhood

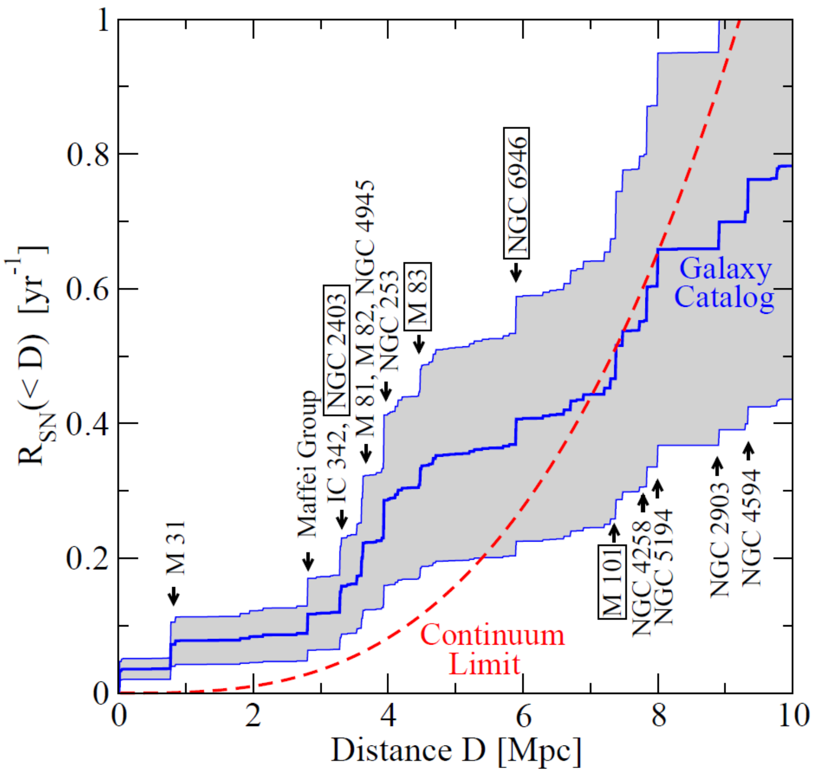
SN 1994D in NGC4526

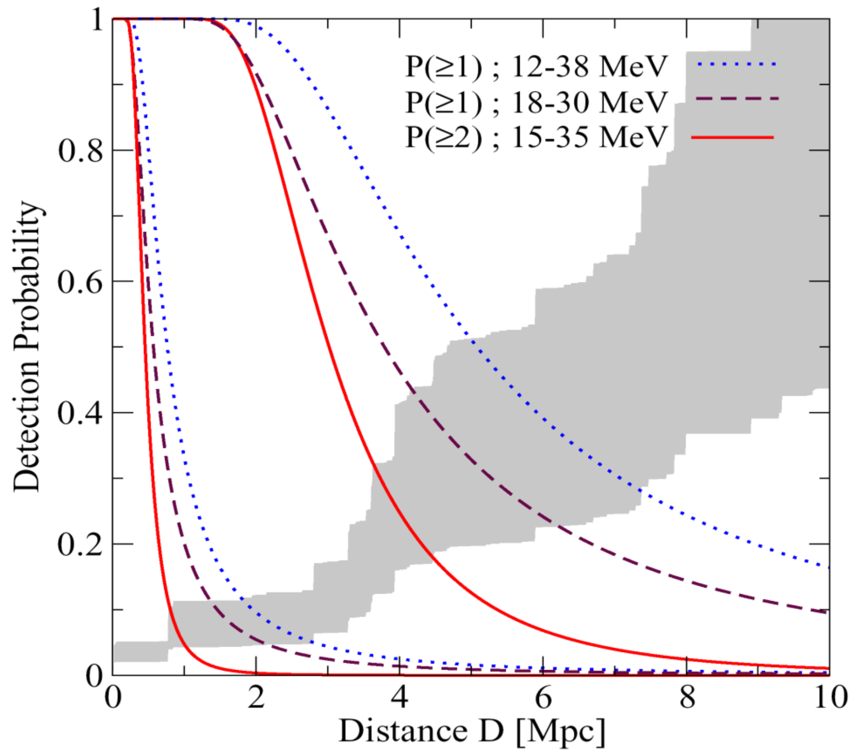




Watching the Neighborhood

Ando Beacom Yüksel



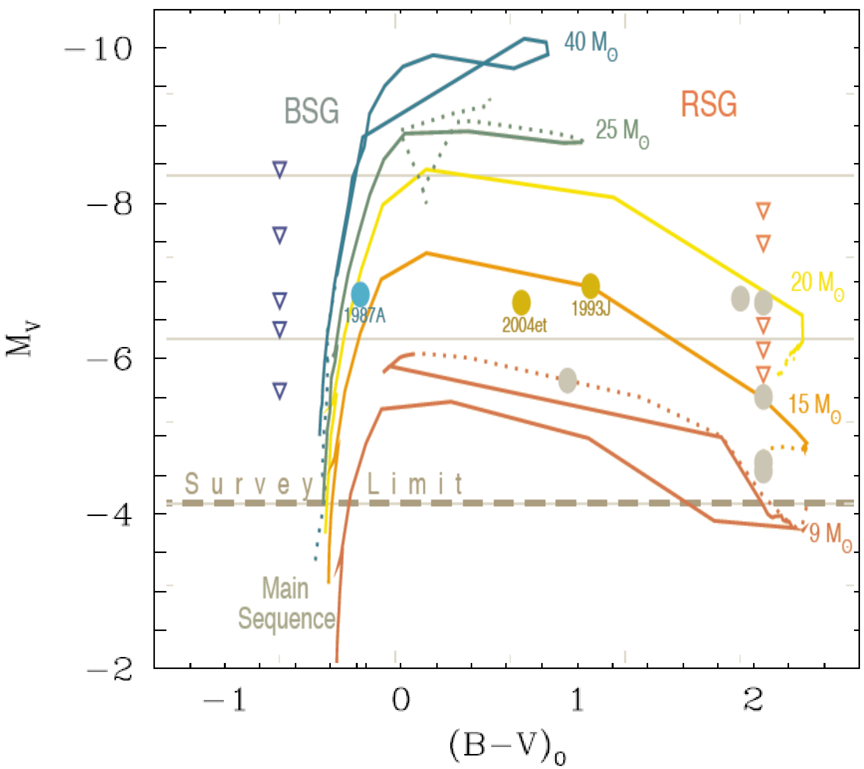


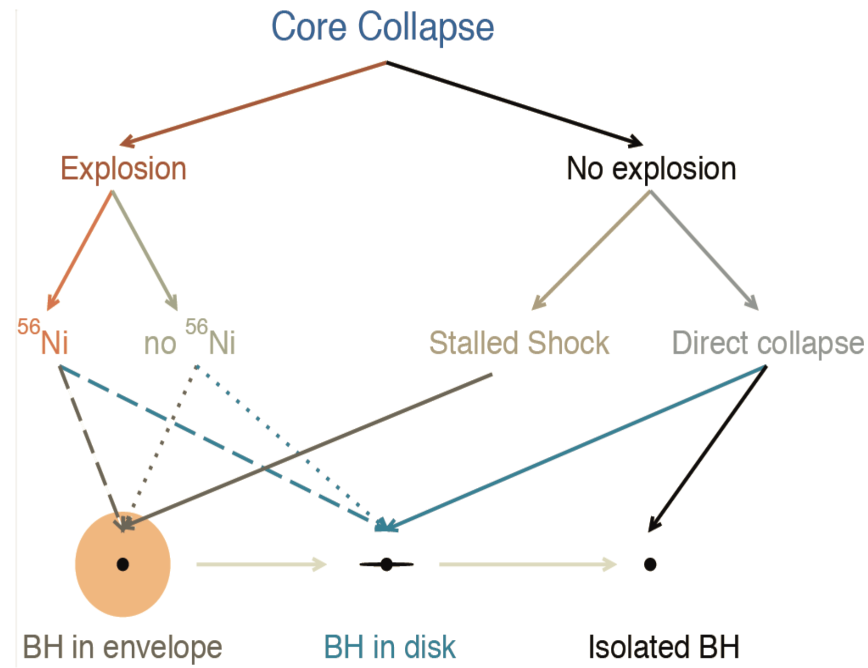
Timing information for more speculative signals (GW)

Requires large detectors: [> 0.5 Mton] like .. Hyper-K, UNO ..

A SURVEY ABOUT NOTHING: MONITORING A MILLION SUPERGIANTS FOR FAILED SUPERNOVAE

Christopher S. Kochanek[1,3], John F. Beacom[1,2,3], Matthew D. Kistler[2,3], José L. Prieto[1,3], Krzysztof Z. Stanek[1,3], Todd A. Thompson[1,3], and Hasan Yüksel[2,3]

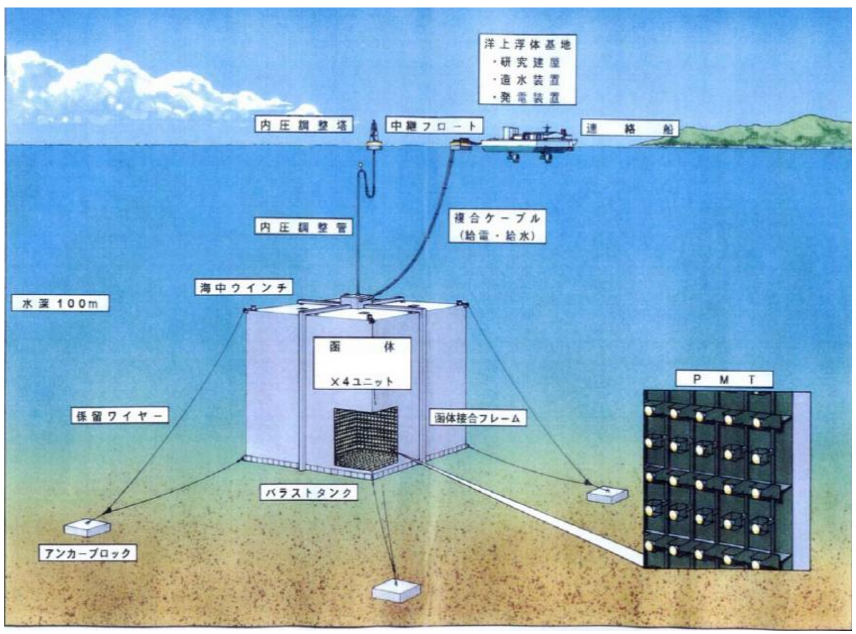


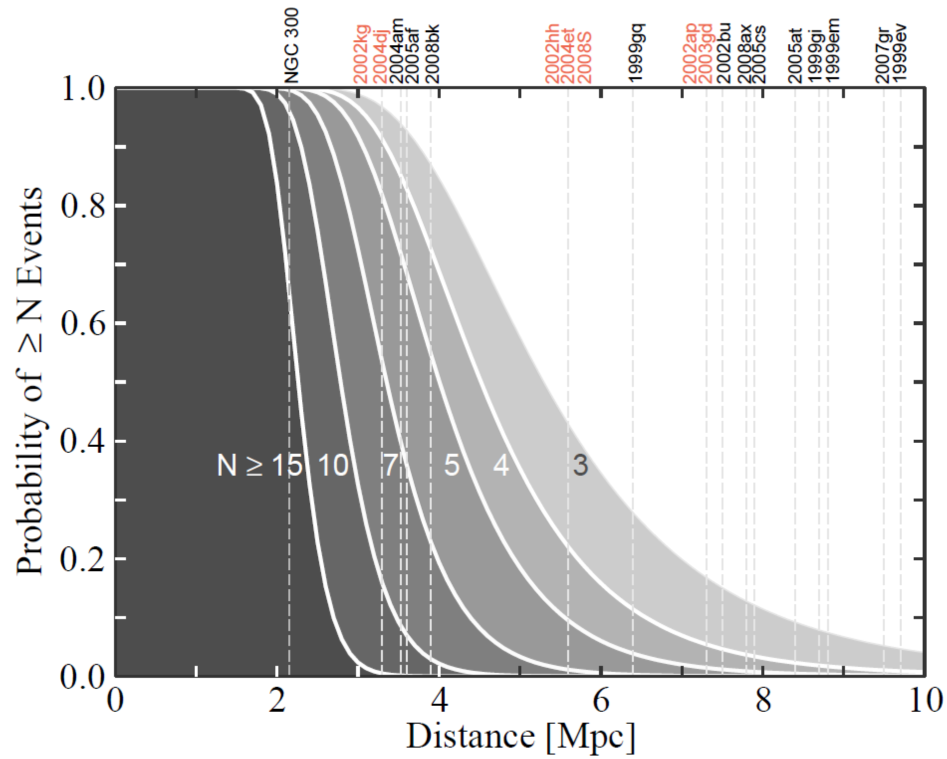


- ~10 meter class telescope can watch most of the massive stars (in 30 galaxies) within 10 Mpc
- look for disappearing Stars which may directly go to black hole
- plus all other potentially surprising discoveries

Core-Collapse Astrophysics with a Five-Megaton Neutrino Detector

Matthew D. Kistler,[1,2] Hasan Yüksel,[1,2] Shin'ichiro Ando,[3] John F. Beacom,[1,2,4] and Yoichiro Suzuki[5,6]

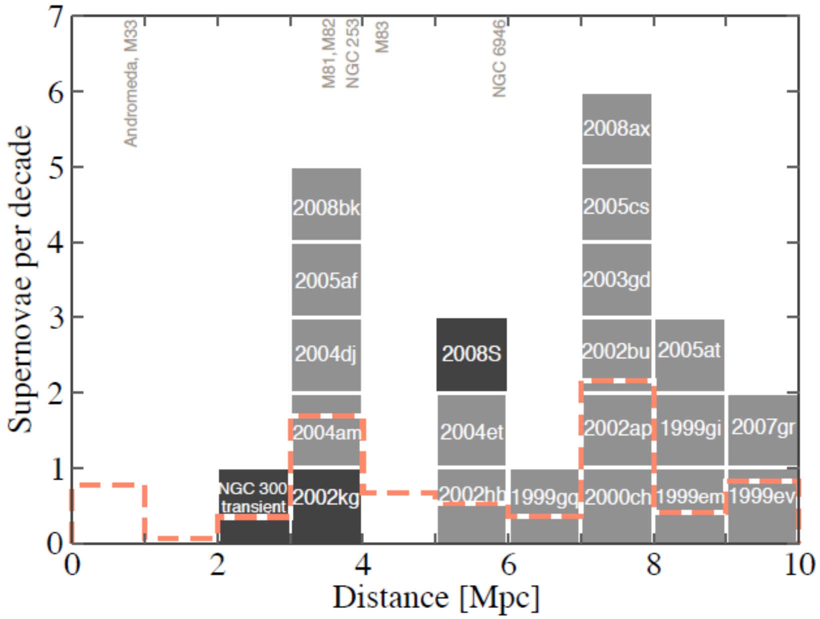


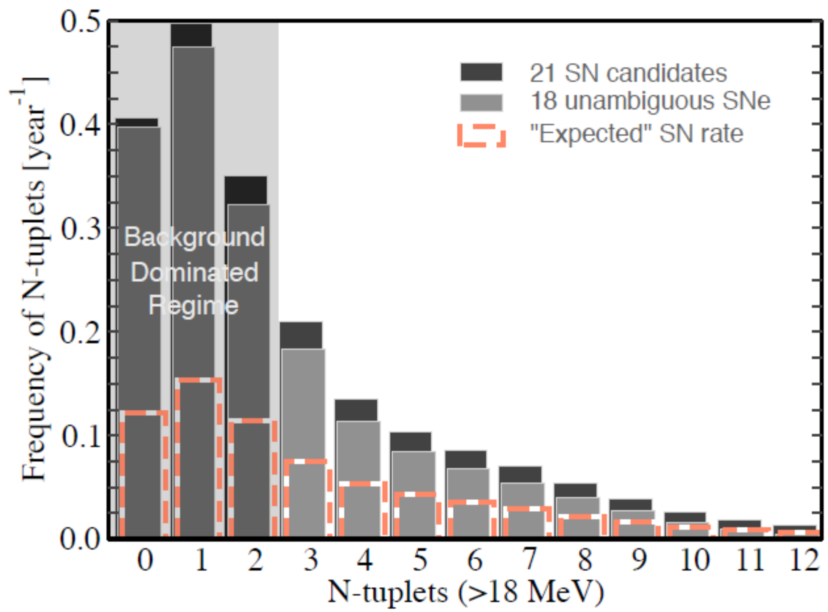


[Deep-TITAND]

"Mini-Bursts" of Neutrinos can be detected Occasionally

If we had this kind of detector in the last 10 years, neutrino yield could have been between 20-40





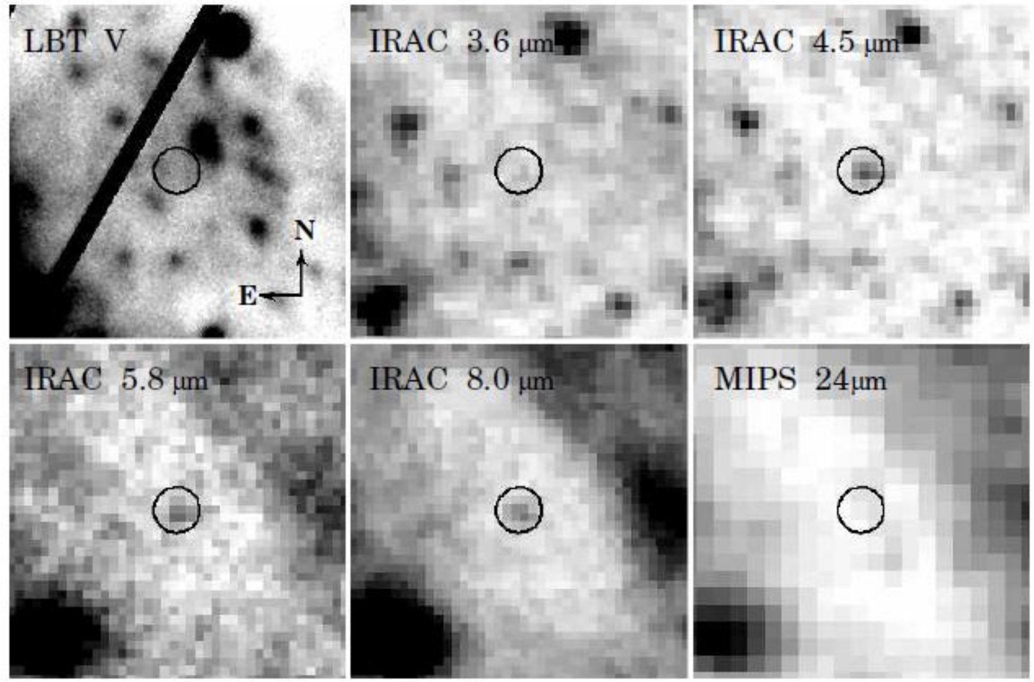
Unique capabilities and science prospects will remain important even if the DSNB or a galactic SN will be discovered

DISCOVERY OF THE DUST-ENSHROUDED PROGENITOR OF SN 2008S WITH *SPITZER*

José L. Prieto[2,4], Matthew D. Kistler[3,4], Todd A. Thompson[2,4], Hasan Yüksel[3,4], Christopher S. Kochanek[2,4], Krzysztof Z. Stanek[2,4], John F. Beacom[2,3,4], Paul Martini[2,4], Anna Pasquali[5], and Jill Bechtold[6]

NGC 6946

SN 2008S



Could this be an O-Ne-Mg Supernova produced by ~10 solar mass progenitor or even an LBV outburst?

Only Nus can tell for sure..

Supernova Neutrino Frontier

- <u>Milky Way Supernova</u>: long wait but big payoff
- <u>Diffuse Supernova Neutrino Background</u>
  [neutrino emission per SN] x [star formation (supernova) rate]
  - DSNB predictions are fairly close to Super-K upper limit
  - Steady source and imminent detection in the near term
  - Astronomers will measure star formation rate better eventually
  - DSNB can test neutrino emission per supernova
- <u>Nearby Galaxies</u>:
  frequent supernovae but require Mton-scale detectors
  - New telescopes, optical and neutrino, will allow a complete characterization of stellar end states
  - Crucial tests of neutrino signal even if there is a Galactic SN
  - Exact timing for more speculative signals (TeV neutrinos, GW)

Neutrino Astrophysics Frontier

- DSNB provides robust predictions for near term discoveries, which is complimentary to other signals:
  - TeV neutrino sources: <u>AGNs</u>, <u>GRBs</u>
    - Icecube almost finished (others planned in Mediterrenian)
    - Promising TeV gamma ray sources by HESS, Milagro, Veritas
      $\rightarrow$~few sigma detection prospect of a TeV neutrino source in ~5-10 years for a hadronic source
  - GZK neutrinos from photo-pion losses of <u>UHECR</u>s & similar
    - Most optimistic GZK flux estimates are testable with ANITA
    - Need higher sensitivity to test other scenarios (Next Generation ..)
  - Neutrinos (gamma rays) from <u>Dark Matter</u> annihilations
    - Require huge boost factors / Hard to beat backgrounds
- DSNB may yield first Neutrinos from cosmological distances